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Outline

OUTLINES

OF THE HALF-COURSE IN

NATURAL HISTORY 4,

WITH REFERENCES TO

DANA'S MANUAL OF GEOLOGY,

AND NOTES.

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OUTLINES OF NATURAL HISTORY 4.

INTRODUCTORY.

The Earth.

HOW REGARDED. *Dana, pp. 1-2.*

Earth is to be treated as a mechanism which has a history; as a theatre (1) of the application of force, (2) of the development of life. It is as truly as is the steam-engine, a mechanism which is applying solar force.

Kepler's idea of the earth as a living, breathing creature is nearer right, than that of an utterly inanimate mass.

RELATION TO UNIVERSE. *Dana, p. 3.*

Three proofs of Earth's kinship to plants :—

(1) Telescopic—spherical form, continents and volcanos.
(2) Meteoric— elements and laws of crystallography same.
(3) Spectroscopic—elements of sun, etc., same as those of earth.

AIM OF GEOLOGY. *Dana, pp. 4-6.*

I. PHYSIOGRAPHIC GEOLOGY.

Earth's Contour and Surface Divisions.

ITS FORM. *Dana, p. 9.*

Flattening of earth is correlated with its rotation, being just what would result from earth's present angular velocity in a liquid globe of same size and density. This gives proof of the present or former molten state of the earth.

LAND AND WATER. *Dana, pp. 10, 13.*

From the cooling and development of an original nebulous mass, there results a solid surrounded by two oceans, of water and air, respectively. Much depends on the interaction of these two oceans, one partially, the other entirely covering the earth's surface. We see on surface of globe a great land-mass about No. Pole from which three triangles project southward into mass of water about So. Pole. Note that oceans keep practically same level, while lands rise and fall. Two great geologic forces are constantly at work on land, those above and at sea-level being acted on by *erosion*, the destructive force, and those below sea-level being subjected to *deposition*, the constructive force.

DEPTH OF OCEANS. *Dana, pp. 11, 12.*

Note that this is on the average much greater than the elevation of land-masses.

SURFACE RELIEFS. *Dana, pp. 15-23.*

Substitute for definition of *mountain*, as follows:— *A mountain* is a ridge of the earth's surface in which at least a part of the relief is due to the folding of strata.

A hill is a relief caused by the cutting away of parts of strata by erosive action, leaving remainder as an elevation.

A volcanic cone is an elevation produced by a deposit of substance ejected from a crater.

SYSTEM IN EARTH'S RELIEFS AND FEATURE-LINES. *Dana, pp. 23-38.*

Dana has been chief student of this subject and has given it undue prominence here. Read especially "Law of the System," p. 23, and "Recapitulation," p. 37. Great exception to general N. W. and N. E. trends is the Indo-European mountain system which trends E. and W.

ATMOSPHERIC CURRENTS. *Dana, p. 43.*

These give us key to oceanic currents and are therefore taken up first. If we had no atmosphere of air, we should have one of steam as a result of the sun's heat

which is sufficient to melt 8000 cu. mi. of ice, daily. Were there no transportation of heat, the temperature of the tropics would be perhaps 150° and that of the poles — 50° F. This would leave but a narrow belt where life could exist and it would probably be kept off there by furious winds. But since air is easily penetrated by direct heat and holds that which has entered it, lower air at Equator becomes very much warmed, and rises, causing an inflow of cooler air from poleward regions, to balance which an outflow towards poles takes place in upper air. This would give north and south winds toward the Equator in the tropics. But as earth's rotation causes an effect like that of a turn-table, throwing moving bodies on its surface to the right of a direct course, these currents of air are thrown to right, and N. E. and S. E. wind produced, known as the Trades. But air is a very poor conductor of heat and acts to equalize temperature only in a secondary way.

OCEANIC CURRENTS. *Dana, p. 38.*

Trade winds blowing steadily over the oceans within the tropics toward N. W. and S. W. cause, by their constant brushing over the surface, strong currents in the same directions, which meet near the equator and flow out on a westerly course. If earth's surface were wholly water this current would simply follow the equator, but being broken up by continents, it is turned N. and S. and carries into Temperate and Polar regions vast quantities of heat.

Thus in Atlantic the equatorial current splits on C. St. Roque, and losing influence of trades, a great current is carried by its own inertia up the western shore and across the ocean to its northeastern shore, and on in part, into the Arctic Zone. A part of this great "Gulf Stream" returns along the coast of Europe, but much the greater part returns along the bottom of the ocean, as a slow, cold current. Dr. Croll has shown that the Arctic Zone gets

more from Gulf Stream than from sun directly, and many parts of the earth are made habitable by warm currents. Since Cape St. Roque is some distance south of equator, the No. Atlantic O. gets more than its share of the equatorial current. To this fact is due the climate of England and her history. Great Japan current of the Pacific does not send any branch into Arctic O. If Alaska were below the surface this would happen; and this may perhaps explain the former mild climate of Greenland.

Gulf Stream had long been known in a general way, but was first definitely studied by Benj. Franklin, though he never clearly published his results. First careful study of ocean currents was by Maury, who plotted them from study of a large series of ship's logs. He believed them caused by greater height (17 ft.) of water at equator than at poles, due to its expansion from greater temperature at equator. Dr. Croll has shown that this gradient is incompetent to produce the known results.

WAVES are also caused by winds, but are only undulations not implying motion of translation. Their effect is to strike a blow.

CLIMATE. *Dana, p. 43.*

Land climate is result of interrelations of water and heat, and furnishes greatest extremes. Sea climate is much less variable. As an example of effect of absence of water, moon's surface is dead, without atmosphere or life. Only changes there are due to expansion and contraction caused by enormous daily extremes of temperature (perhaps 1000° to — 200° F.)

At the critical point of 32° F. the influence of water is wholly changed. Above, it is a liquid, readily absorbed and essential to life; below, it is a very slowly moving solid, fatal to life.

DISTRIBUTION OF FERTILE AND STERILE LANDS. *Dana, p. 44.*

II. LITHOLOGICAL GEOLOGY.

Rocks. *Dana, pp. 47, 62.*

This term is used to include all the materials of the earth's mass, excepting imbedded ice. Rocks give us the chief points in the study of the earth's physical history, while their contained fossils furnish much of the history of life.

They may be divided into two great groups, according to their origin.

MINERAL ROCKS are those which have originated solely from physical and mechanical causes, including by far the greater mass of rocks, the sandstones, granites, etc. According to structure they may be divided into two groups:

Fragmental rocks, formed of broken fragments of various rocks, are produced wholly by action of celestial forces working through water. These include sandstones, shales, etc. As soon as laid down these rocks become subject to action of terrestrial and celestial forces, for as new strata are laid down over them, the effect is to raise the temperature in lower strata in the same way as if a series of blankets were piled up over them, each new blanket serving to raise the temperature at any given point. This *blanketing* thus causes the lines of equal earth temperature (isogeothermal lines) to rise, and as a result of increased temperature and pressure the fragmental rocks become slowly changed to the second or *crystalline* form which is the state of rest of rock material.

Crystalline rocks include granite quartz, schists, etc. The effect of erosion on these rocks is to carry them back to the fragmental form, thus completing the cycle.

ORGANIC ROCKS owe their origin to physical and organic causes combined, and consist almost wholly of compacted remains of organisms. They include the limestones.

ELEMENTS IN ROCKS. *Dana, p. 48.*

Add to those enumerated by Dana, phosphorus, the relation of which to life will be noticed later.

DISTINCTIONS IN STUDY OF ROCKS. *Dana, p. 63.*

Note that specific gravity of rock is necessarily greater than that of water; otherwise the earth's machinery must be stopped. Note carefully descriptive terms, p. 66.

Conditions and Structure of Rock Masses.

STRATIFIED CONDITION. *Dana, p. 79.*

Stratified rocks are those arranged in layers, in whose deposition there has been an element of gravity. They may be formed in three ways: (1) by falling of matter through water to bottom; (2) by falling of matter through air, as from a volcano; (3) by lava flow from fissure or crater.

A *layer* (*p. 81*) is the structural unit in stratification; it indicates the the continuation of certain forces for a time, followed by a change.

A *formation* consists of several or many strata of many layers each. It is less clearly marked than a stratum, which is not so readily distinguishable as a layer.

STRUCTURE OF LAYERS. *Dana, p. 82.*

Of structures originating in the act of deposition, the laminated and shaly, separated by Dana, are practically the same. Compound structure is due to the action of winds, waves, or currents. Strata formed by the wind are of uniform, fine material; those formed by water may be of various materials. Strata formed by regularly flowing currents are of an uniform inclination, while those formed by tide currents or waves may be very uneven and broken.

Ripple marks (*p. 84*) indicate the presence, at time of their formation, of shallow water and a current, but not necessarily of a beach, since they are known to be formed in water 200 ft. deep. They are like marks formed by wind on sand or snow. How this action starts and what determines height and distance of ridges is unknown, though it may be a rolling motion of air or water. Both measurements are greater in water than in air.

Mud-Cracks are such as are commonly formed under a hot sun on muddy shores, and are often and easily fossilized by being filled with blowing sand or some other substance, and then buried under fresh mud.

Rain Drop prints are well preserved on some old beaches; from them we can often tell the direction of the wind during the shower, by the splash on the leeward side of the print.

Of structures of origin subsequent to laying down of strata:— the concretionary structure (*p. 85*) somewhat resembles the crystalline, but differs in that crystallization takes place in accordance with mineral species, at high temperatures, and results in definite geometrical masses, while concretion takes place more with reference to substance of matter deposited, at lower temperatures, and results in amorphous masses. Concretions often begin about an organic nucleus. Sometimes they are hollow or with interior filled with crystals. They often simulate animal forms, as in case of a form found in very old limestones in Canada and named *Eozoön Canadense*, whose true nature was for 20 years a subject of much dispute, many believing it to be the fossil remains of a very simple animal. Concretion and crystallization are the two great causes of metamorphosis in rocks, and are greatly aided by the presence and circulation through the rocks of waters having mineral matters in solution. A similar action is the taking on, by the constituents of rocks, of more of their own material from solutions, thus more firmly cementing the rock together. This is called interstitial metamorphosis.

All but the newest rocks are penetrated by breakage-lines (*p. 88*) usually in different directions, and irregularly placed.

These various planes cut up the rock and facilitate quarrying, where not so numerous as to render the rock worthless. The cause of formation of these "*joint-*

planes" is probably successive enormous pressures to which the rock has been subjected, each set of joint-planes being the index of a pressure at *right angles* to its direction.

Slaty cleavage (*p. 89*) is also caused by pressure, but differs from jointed structure in having its planes close together and in a single direction only. The rocks in which this structure occurs were formerly clayey mud which contains much mica in tiny particles. Pressure on this mud would bring the bits of mica more nearly parallel and start fracture-lines.

Movements of rocks on each other cause groovings, polishing, etc.

POSITIONS OF STRATA. *Dana, p. 91.*

Natural position of strata is horizontal, the tendency being to level irregularities, and, on an inclined surface, to form an incline of less angle. River-deltas, however, form beds which, at their further ends, have steep slopes.

Dislocations of strata caused by powerful forces are common, and of several forms. The simplest is the fold, which may be simple or modified by subsequent greater folds, or may be collapsed, that is, pressed together till there is no longer resistance to pressure and its sides meet, the whole fold falling over sidewise. The line of direction of the fold is called its *axis*. An upfold, with sides sloping away from a ridge is called an *anticlinal;* a downfold with sides sloping into a trough, a *synclinal*. The compass course of the axis of a fold is its *strike*, while the slope of its sides is the *dip*. These folds, etc., are negative results of the cooling of the earth's interior and consequent shrinkage and packing of the crust to accommodate itself to a smaller nucleus.

Faults are usually results of similar forces to those causing folds, and occur where rocks from their structure or from being thick-bedded, do not readily bend under pressure, but rend apart. Faults very commonly follow

joint planes, and may be of any size. In most cases there has been, in addition to rending, a slipping of rocks on opposite sides of the fault upon each other and this sometimes amounts to thousands of feet, bringing strata of very different age on to same level. Fault-planes may be located, like folds, by dip and strike. The portion of rock faulted out of place is usually wedge-shaped, and in a large majority of cases the strata have been pushed in the direction indicated by the point of the wedge. Since a joint-plane is commonly a warped surface the result of slipping of rocks is often to form open spaces where sides fail to fit closely, and many mineral veins have originated in this way. Another form of fault is caused by splitting of rock mass from shrinkage, forming "Gash-cracks."

Even the hard rocks are fluid to sufficiently great pressure and may be shown to have been compressed so as to be increased many times in length, by distorted fossils found in them. These can be recognized when extended to three or four times their length, but beyond this become mere blurs. One of the hardest tasks of the Palaeontologist is the reconstruction of distorted fossils.

Great sources of error in study and practical estimation of strata are folding and faulting, by which a single stratum may be brought to surface at several points and so made to seem like so many strata. The geologist avoids error of this sort by carefully noting the thickness of seemingly different strata as well as the character and thickness of beds immediately above and below them. Similarity in these data indicates pretty surely the identity of what seem to be distinct beds.

Effects of denudation and conformable and unconformable strata are sufficiently treated in text (*pp. 96, 100*).

ARRANGEMENT OF STRATA. *Dana, p. 101.*

Means of determining the order of arrangement of strata

are several, but the most important is the study of their fossils. It was suggested 200 years ago by Dr. Hooke that it might be possible to "raise a chronology" from the study of fossils, but nothing was done until the beginning of the present century, since which time it has been shown by careful study of fossils that there have been many nearly complete changes in the organic life of the earth's, surface. This was long believed to be due to the sudden extinction of life and the subsequent creation of new forms; but it is now believed that at various times new forms have arisen from existing forms by rather rapid changes and modifications, though we cannot say what forces have determined these changes. The study of these organic remains enables us to identify layers or beds of the same approximate age, to study ancient climates from the distribution and limits of species, and to study the currents of the ancient seas, and from them continental lines, chiefly from remains of reef-corals which require food-bearing currents for their growth.

From these studies, materials are accumulating for a complete history of the ancient conditions and changes of the earth, since organic life, on account of its delicacy and impressibility, preserves for us in its remains, records of many important facts of which the rocks give no hint. But the old idea that similarity of species of fossils in two layers indicates identity of age must not be too much trusted since a given region of the globe may have had at one time a very similar fauna to that of another region at a very different geologic period. For instance, as we go away from Europe we find life differing more and more from the life of that continent, and find that the present fauna of N. A. much more closely resembles the Middle Tertiary fauna of Europe than that of to-day, while the present Australian fauna is very like that of Europe in the Jurassic period.

It should be noted that fossils "of the same age" may

represent organisms which lived thousands of years apart, but under similar terrestrial conditions, that is, in the same geologic period. Fossils of the same age or geologic period are said to belong to the same "*horizon*."

UNSTRATIFIED ROCKS. *Dana, p. 107.*

These rocks may be divided into three classes; (1) lavas which have flowed from craters; these sometimes present a stratified appearance from the superposition of successive flows, and on the other hand some bedded rocks have been so metamorphosed by heat as to resemble lavas; (2) lavas which have flowed between bounding walls of rifts, forming dikes; and (3) deposits from solutions in water, such as those of mineral matter in veins. To these may be added for convenience, glacial drift which owes its origin to cold, while those properly belonging here are the result of heat-action.

DIKES AND VEINS. *Dana, pp. 108-113.*

Both these formations originate as rifts or cracks in the rock, caused by faulting or otherwise, and usually following joint-planes which become filled by different mineral substance.

Dikes are formed of full width from the first. When a series of beds, with a rift, becomes greatly heated by the blanketing effect of strata lying above, and one bed, being more fusible than the rest, becomes melted, the effect is to at once force this molten material upward into the rift, with or without volcanic action, filling the rift and forming a dike, which usually does not extend to the surface and is not exposed until the overlying strata have been planed away, ages later. Dikes are usually vertical and often very irregular; they frequently intersect, when their relative ages can be made out.

Fissures not filled by dike-material are sure to be sooner or later, by slow process, filled with deposits from percolating water, forming veins. These fissures may be formed at first of their full width, but oftener they are

gradually spread by the force of deposition and crystallization of substances within; this is called interstitial growth. All substances are found in sea-water in some quantity, it is supposed. These are taken up by plants and animals, as for instance, lime salts by corals, mollusks and others; soda and potash by sea-weeds; and nearly all elements in minute quantity by various forms. When these plants and animals die and decompose, these elements become a part of the rocks. This may be termed the first concentration of the elements. When deeply buried in the rocks, where the water has a solvent power equal to that of the strongest acids, due to its great temperature and pressure and large proportion of CO^2, these substances are dissolved and the percolating water becomes charged with them. Here we have the second concentration. If now we have a series of beds with one or more rifts or cracks running through them, we shall find this saturated water working downward through the permeable strata, which are bordered by impervious ones, until it reaches the rift, through which it will rise rapidly, depositing on the walls the substances held in solution, in the order of least solubility, and so forming veins of metals or other substances. The forces which cause constant percolation of water through the rocks are: (1) Gravitation; (2) Osmosis; and (3) its tendency to penetrate towards a centre of heat.

DYNAMICAL GEOLOGY.

(*Dana*, *Part IV*, *p. 605*.)

Energy from the celestial spaces as applied to the earth's surface may be divided into two classes:—the generalized, physical forms, the winds, currents, etc.; and the localized form, seen in organic life.

Life. *Dana, p. 606.*

An organic form may be defined as a form of matter which has the power of taking into itself matter from without, and of utilizing its material and *force*. The work of earth-building depends on the interaction of organic and inorganic forces. The tendency has been to belittle the influence of organic life in this matter, but it is true that hardly any existing rock would be in just its present condition, but for this influence. In crossing North America we are for more than half the distance on rocks which are largely the result of organic life, and it may even be said that our continent owes its present form to this really powerful agent.

ITS PROTECTIVE EFFECTS. *Dana, p. 607.*

The most important protective effect of vegetation is to protect soil and roots from the washing effect of rains. A ploughed field loses much of its loose surface-soil with every rainfall. As the vegetation depends for its nourishment largely on the soil, so it protects itself by holding the soil, and a given piece of ground depends for its soil on its vegetation. Thus the two are interdependent. Sea-weeds protect the rocks on which they grow by preventing the water left in the crevices from freezing at low tide and rending the rocks. Our salt marshes of the New England coast are not merely protected, but have been won from the sea by maritime plants, chiefly grasses, rushes, and sedges.

ITS TRANSPORTING EFFECTS. *Dana, p. 607.*

ITS DESTRUCTIVE EFFECTS. *Dana, p. 607.*

These are better called *Metamorphic* effects of life, in harmony with the modern idea of our world, that of change, rather than of destruction and death.

Decay effectually attacks only exposed surfaces of rocks. Roots in their growth split rocks and thus expose more surface for erosive action. A cubic foot of rock broken up into cubic inches has more than ten times as much

surface as if in a single cubical block. Thus plants help to make the soil they need. If the Colorado cañons were grown with vegetation, their vertical walls and sharp angles would be lost, from the rounding and eroding action due to the leverage of plant-growth.

Earthworms do a great work in changing the surface of the ground. Mr. Darwin has shown that they average 40,000 to each acre of arable soil; and these pass through their digestive systems for the sake of the organic matter it may contain, many tons of earth per year which is left at the surface of the ground, so that thus the surface is often completely changed. Thus, also, stones and small objects soon become buried and Mr. D. believed that even some of the rural churches of England had been undermined and caused to sink noticeably by earthworms. A similar action is going on, by worms, on the sea-floor. Ants also do a similar, but less extensive work.

After life is extinct, many organic forms have much effect. Many growing trees shed during their lives woody matter of twenty times their own bulk, yet there remain at the base, but a thin layer of vegetable mould, whose constituents are constantly being absorbed by rowing plants, while the great bulk of the constituents of the original wood has passed into the air and been more or less absorbed by plants, in the gaseous form. Thus the dust to which we return is but a transient passing stage between life and life.

ITS CONTRIBUTION TO ROCK-FORMATIONS. *Dana, pp. 608-626.*

These take place chiefly under water where decomposition is slow and imperfect. Here plant and animal remains become enclosed in the rocks as stored-up carbon, in form of coal, limestone, etc.

On land, one of the chief forms of deposit is the peat-bog. These are formed in small ponds which become gradually filled up by the growth of peat mosses.

Starting from the edge of the pond, these mosses, chiefly of the genus *Sphagnum*, grow out slowly into the pond, growing upward and dying below, and forming a tangled, closely matted mass, which holds water like a sponge. This water admits of but very slow decay of the dead moss, which gradually falls to the bottom and forms a layer of black mould, between which and the sheet of moss is a layer of water. But the growth of the moss increases the thickness and weight of the sheet, and finally it reaches the bottom, filling the basin. As the moss is very yielding, the growth always forms a very treacherous bog. In some bogs in Northern N. A. the Sphagnum may grow up a slope for a few feet, but in Europe are bogs which have spread hundreds of feet from the original edge of the pond. These are called *climbing bogs*. They sometimes become so filled with water in heavy rains as to burst and flood the surrounding country with black mud.

A peat-bog must have one of two fates. It may be quickly lowered beneath the sea and then buried under rock strata, to form a coal bed under influence of heat and pressure. If slowly sunk, it will be destroyed by wave-action. Or it may remain above the sea-level, and be finally drained by cutting down of surrounding land. Then the dried peat will decay and return its stored carbon to the air. As temperature of tropics causes more rapid decay, no important bogs or coal deposits are found there. Peat bogs and coal-deposits are often underlaid by thin strata of so-called "*infusorial earth*," which consists of remains of microscopic plants and animals which lived in the pond that preceded the bog.

In the sea, the less complete decomposition of plants and their different composition result in the deposition of carbonaceous shales. A large deposit of this sort in the Ohio valley represents an old Sargasso sea. It is very rich in coal-oil products and was quarried for distillation, before the introduction of bored wells.

Animals leave deposits of mineral matters taken up by them during life, especially carbonate and phosphate of lime, and silica. Phosphorus, though existing in such small quantity, is essential to the animal organism: it enters into the constitution of bone, and is intimately connected with the working of the nervous system; it is secreted especially by the King Crab (*Limulus*) and the Brachiopods. Carbonate of lime is secreted by many forms. It is deposited on the floor of the deep sea chiefly by the tiny Foraminifera which live at the surface and whose dead shells and tests are constantly raining down upon the bottom to add to the slowly growing deposit. But shallow water deposits are due to fixed animals, and especially to corals.

Rising from the sea-floor in the So. Pacific O. are many mountain-like masses with steep slopes, coming above the surface as ridges enclosing shallow basins of water. These are solid masses of carbonate of lime in the forms of coral skeletons, with living corals at the top, and are called coral islands or atolls. The sea is constantly wearing away these masses by its beating on the outside, while the basin or lagoon within is quiet, though connected with the ocean by one or more openings, usually on the leeward side. On the ridge above water is found a beach of white calcareous sand, and above a wind-piled heap of this sand covered with a vegetation chiefly of palms. On the outside of the reef where the sea beats strongest are found the dome-shaped corals which can withstand the waves (Maeandrina, Astraea, etc.); in more protected situations are the branched forms (Madrepores), while in the inner basins are many very delicate corals and other animals. The crevices and tide pools everywhere swarm with various forms of animal life suited to them.

Along the N. E. coast of Australia is a great wall of coral over 1000 mi. long and several thousand feet high, known as the Australian barrier reef.

These coral reefs and islands depend on a sufficiently rapid growth to counteract and to gain on the wearing action of the sea. Their existence depends on the possibility of the association of numbers of individuals in colonies and on the presence of currents bearing sufficient food and warmth (70—75° F.) to support these colonies in their growth and to supply the immense energy expended by them.

Atolls were at first believed to be formed by masses of coral growing on sunken craters of old volcanos, since corals cannot live at a depth greater than 100 feet. But dredging showed the whole mass of the cones to be composed of coral, and Mr. Darwin began to collect data concerning them. He found that, while most of the atolls enclose open lagoons, some of them have islands of volcanic rock in the centre, and in other cases the island is a mass of rock closely fringed by coral, without water between.

From these facts he deduced the now accepted theory of their origin, that they are coral-reefs which started about the sides of volcanos when they became extinct. As the sea floor slowly sunk carrying down the volcano, the corals grew upward until at last in many cases they alone remain to show the site of the old volcano, while in other cases its top remains as the island in the lagoon. This would indicate a slow and steady subsidence of the sea-floor, as a rapid one would quickly have carried the corals beyond their depth; and we have a good illustration of the normal subsidence of the sea-floor caused by the cooling of the earth's interior, and resulting in a decrease in the earth's diameter of one to three feet in one thousand years.

From old coral-reefs we can determine the set of ancient currents and from the latter, the conformation of land masses; so that fossil coral-reefs give us valuable aid in plotting the early geography of the earth.

Cohesive, Capillary and Gravitative Attraction.

COHESION AND CRYSTALLIZATION. *Dana, p. 627.*

Cohesion is very variable in rocks, and each rock mass has two elements of cohesion, that of the whole mass, and that of the units constituting the mass. But in a given rock, the cohesion is constant, though sometimes increased or decreased by the effect of crystallizing action. Crystallization acts only till its work is accomplished, a comparatively short time.

Some rock are very elastic and this quality usually increases with density. A species of rock known as *Ita columite* and resembling sandstone, is frequently associated with gold-bearing rock. It is so flexible that the ends of a strip supported at the middle will drop, of their own weight, to a certain point, beyond which, however, they are rigid.

All rocks contract and expand under cold and heat, the amount varying for different rocks. This has to be taken into account in the construction of fortresses and is of much importance in Geology, when we consider the great extremes of temperature through which many rocks have passed.

CAPILLARITY. *Dana, p. 629.*

This has an important effect. On a beach the waves grind up the sand and pebbles much less than they would, were it not for the thin layers of water between the grains, which are held there by capillary action. During long and severe droughts, on salt marshes which have been reclaimed and brought under cultivation, there may be seen efflorescences of salt, brought up from considerable depths by capillary action. Roofing slates are artificially separated by pouring water upon the edge of o block, when it is drawn into the cleavage planes, which were before invisible.

GRAVITATION. *Dana, p. 630.*

This force appears in some way in nearly all motion on the earth's surface, though always in conjunction with other forces. The soil on sloping hillsides tends constantly to slip down. But the chief effect of gravity is to pull down rocks from cliffs or elevations. The "Diablerets" is an amphitheatre near the upper Rhone, on top of whose high vertical walls formerly stood five mountain peaks. The surface on which they rest is soft and slopes inward toward the amphitheatre. Two of these peaks have already leaped off and another will soon do so, having slipped down the slope to the edge. Several destructive falls of this sort have taken place in the Alps. Earthquakes greatly assist in starting an action which gravitation can continue and complete. An important work of gravity is the breaking up of rock masses and so assisting in soil-formation.

The Atmosphere. *Dana, p. 630.*

The atmosphere is interesting, because it is the mechanism through which celestial energy is applied to the earth's surface. All life is absolutely dependent on the atmosphere, aquatic forms depending on the air contained in the water. In keeping the water aërated, storms, which stir it up and cause breakers, are very effective.

The atmosphere is to be considered (1) as a reservoir and (2) as in motion. It is a reservoir of oxygen, hydrogen and CO_2. Oxygen is taken from the air by all living things and by the oxidation of various substances; a small amount is returned by the reduction of oxides, but how the great bulk gets back is not clear. CO_2 is taken by all plants and is returned by decay and combustion.

The atmosphere in motion is the wind. Its greatest authenticated velocity is about 100 miles per hour, though its force much exceeds this in volcanic explosions or rock-falls. The light weight of the air makes its rending power very small; but on soft rocks, sand, driven by the

wind, often has considerable cutting power. Loose sand not held in place by vegetation, as on sea-shores and deserts, is often heaped into hillocks or "dunes." These start like ripple-marks (*v. p. 8.*) and often reach a considerable size. The wind is constantly being blown over the crest from the windward side of these dunes and so they gradually travel across country with the prevailing winds, sometimes overwhelming villages. In this way deserts often extend their limits and so the Sahara has encroached upon ancient Egypt, coming down in places nearly to the Nile.

Fine sand is sometimes carried long distances by the wind and finally deposited, the successive deposits forming, at length, a thick layer over the surface, as in the valley of the Hoangho in China. These, which have been but recently studied, are called "Loess" deposits.

Note.—In the study of Geology we must radically correct our preconceived notions of time and its duration. Our conceptions are based on successions of events and their impressions on the mind; but we must learn to appreciate the stability of inorganic forms and phenomena as compared with the momentariness of organic life, and that geologic time is not to be measured by human life or by the duration of all life.

In considering geologic time we must give up, if possible, our ideas of a beginning and an end, in order to appreciate its vastness.

Water. *Dana, p. 635.*

Water does a much greater work than the air. Its functions are of two sorts, that of *storage* and that of *applying energy*. The former includes its carrying power for heat and various substances; the latter includes its action in falling and is due to heat and gravity.

Substances carried by water may be in perfect solution, so as not to be affected by gravity, or they may be mechanically suspended so that gravity constantly tends to make them settle to the bottom.

Heat causes water to evaporate and rise in vapor to form clouds, in which form it has great energy of position and tends to fall in obedience to gravity. When it falls, it is as rain or snow, and the roles played by these two forms of water are very different. Rain which has fallen is either reëvaporated and reprecipated or else it passes into the ocean through streams, and is there evaporated. By the rainfall of a country may be meant simply the number of times its water is evaporated and precipitated. Forests act as sponges to hold water which has fallen until it is again vaporized and so increase rainfall, but probably do not increase the amount of rain from the ocean on a region. Thus the complete circuit of water is from the clouds to the earth as rain, through the rivers to the ocean and thence back to clouds.

Water at high speed has great energy, whether in waves or current. The maximum speed of currents is about 10-12 miles per hour, and their carrying power increases as the fourth power of the speed.

Water above the sea level has energy of position which it tends to expend by running down to sea, growing less and less powerful as it approaches the sea level.

Rivers. *Dana, pp. 626-663.*

Water, falling as rain, partly penetrates the soil, as ground water, and partly remains as surface water. Of all this water streams carry away from 15% to 25%, the rest being evaporated. A basin of water, the evaporation from which exceeds the supply, becomes a salt lake or *dead* sea. The ocean is prevented from becoming so salt and alkaline by the action of its organic life.

The effect of a stream, (*p. 641*) as soon as it becomes permanent, is to channel out a bed and to cut and leach away its sides. By its action the surface of its valley is lowered about one foot in 5000 years. on an average.

A stream always tends to increase its curves by building on to one bank and cutting away the other until, at last, a bow is formed, with a narrow neck; then the stream cuts through the neck and leaves its old bed around the bow. But a change like this necessitates the reconstruction of all the curves in the river below, since all the curves of a stream have a definite relation. Thus a stream slowly works over its valley, and successive maps of a system at different stages of its history would show very various courses, though each would have a certain relation to the others. The ratio of the leaching action of a stream to its downward cutting depends largely on the character of the bed; in the canon of the Colorado (*p. 645*) the leaching action is almost nothing, from the hardness of the rock, and the river has cut deep gorges, with nearly vertical sides.

The topographic effects of erosion (*p. 551*) are influenced by three factors: the hardness of the rock, the structure of the rock as to jointing, etc., and the attitude of the beds. The second of these determines the amount of rending of the rocks by the penetration and freezing of water. The third also often has much influence on the courses of streams, where there is a tilting of the beds. In such a case, where there is a soft stream lying between hard ones, the former is worn away by the water, and thus the hard layers above are undermined, and at last cave in, so that the bed of the stream gradually works away in the direction of the dip of the strata. Where water flows over folded strata, its cutting action is greatest on the ridge and least on the depressions. This is due to the looser and more open character of the rock on an anticlinal, and its compacted and solid character in a synclinal. These variations in hardness and dip of strata thus can produce infinite variations in details of mountains and rivers, and are of great influence in determining the relief of a region. The above con-

siderations may give us an idea of the wonderful elasticity in the course of a river, and show that the position of a stream at a given time is only temporary and is derived from all past conditions.

The pot-holes in the New England Mts. (*p. 553.*) are connected with glacial action. When the ice-sheet was retreating, near the end of the glacial period, it acted in many places as a dam to block up river-valleys and form great ponds which rose until they overflowed their water-sheds and poured over into the opposite valleys. The rush of these torrents over the ridges, during the time when their outlets were dammed by ice, was the cause of the formation of these pot-holes.

The transporting effects of rivers (*p. 553.*) vary much with the characters of their valleys and other conditions, the long streams carrying out much more material in proportion than the smaller ones. It was formerly believed that a large part of the sediments of rivers are carried far out to sea, but it is now known that sea-water has the peculiar effect of causing the precipitation of substances at a very rapid rate, so that little sediment is carried far beyond the mouths of streams. Substances not merely in suspension, but truly dissolved in water may be carried any distance. This deposition of sediments is important in enabling us to make out old river deltas, from the structure of the strata, which always show considerable woody matter and also cross bedding of layers of sediments. From the study of old deltas in connection with present geography, much can be learned of the rivers which formed them. Thus Gay Head, Mass. is part of the delta of a large river which once drained New England, and perhaps west to the Hudson River; and the Isle of Wight is formed by delta-deposits of the old Rhine, when Great Britain was a part of the continent of Europe.

SUBTERRANEAN WATERS. *Dana, p. 663.*

Underground water may be divided into three classes; that which penetrates the soil only; that which penetrates the rocks, flowing characteristically in channels, but never going below the drainage-level; and that which does go below the drainage level through pervious layers, returning by fissures or faults. These may be called respectively *soil*, *rock*, and *deep-rock* or *siphon* waters. As the siphon water goes down through the rocks, its solvent power increases, and when it rises it must deposit much matter from loss of this solvent power.

Only rock water can have any mechanical effect, and it can do so only when it is in considerable streams, moving with some rapidity. In such cases it often forms large caves, though a part of this action is due to its solvent power.

In basins which have pervious layers overlaid by impervious ones and which are fed from high land, the sinking of a shaft which penetrates to the pervious water-bearing layer will allow the water to escape in a jet to a considerable height, depending on the height of its source. Such borings are called Artesian wells, from Artois, near Paris. The same effect is occasionally produced on level ground by the pressure of enclosed gases, on the principle of the soda-fountain, and as in the case of oil-wells.

THE OCEAN. *Dana, pp. 668-687.*

Probably 99 per cent of the water on the earth's surface is now in the ocean, although when a great amount was locked in ice, as in the last glacial period, perhaps not more than 97 per cent was in the sea.

The greater part of the force applied in various ways by the ocean comes from the stellar spaces. The winds, produced by variations in temperature, cause two sorts of motions; the constant or trade winds produce the currents of the sea, and the temporary winds produce waves. The attraction of the moon causes the tides which are the only

important effect on the earth of the gravitative force of another planetary body. The tidal wave is normally 6000 mi. broad and one foot high, and its swing is about 250 feet each way in 12 hours. Such a slow motion would not stir the sediments of the sea-floor. The earth's loss of heat causes earthquakes which lift the whole mass of water over the shaken area and cause waves to run out from this centre which may run around the earth as in case of the Krakatoa earthquake. The top of a tidal wave moves faster than its lower part and its front faster than its rear until the shore is reached when the back parts gain on the front and pile up, often running far ashore. An earthquake wave is usually higher than a tidal wave but of less extent, while both affect the whole mass of the water. Earthquake-waves stir up the bottom, to the great destruction of bottom-life, and from their frequency on the west coast of South America, very few animals are there found on the bottom. Tidal waves, on the other hand, by their gentle motion serve to bring food and distribute their reproductive elements for sessile, bottom-inhabiting creatures, which are thus very dependent on them.

The erosive effects of ocean currents are of no importance. Wind waves often run for miles before reaching a shore, and then have little effect unless they are armed with fragments of rock. But if furnished with this means they can cause very rapid wearing and destruction even of hard cliffs. This work of wearing goes on, like a great mill, along all shores, but with various results. The south shore of Martha's Vineyard is being cut away at the rate of two or three feet per year; the island of Helgoland is only one-eighth as large as when first known to history; while some rocky shores where water is deep are little affected. Dikes of soft rock are often cut out of harder wall-rock, forming caves and chasms. Sand beaches are formed in recesses of the coast by deposits of detritus from bounding headlands, if the waves strike the headlands ob-

liquely, so as to carry in the eroded matter. But if the waves strike at right angles to the shore, the products of erosion are carried back by retreating waves. A beach grows rapidly if the material brought in exceeds the wear caused by the waves and rolling stones on its surface, until it has come to so protect its headlands that an equilibrium is established. Beaches sometimes are so oversupplied that they have to overflow into adjoining bays or bends of the shore. Tides heap up rapidly in running into narrowing bays or inlets. An example of this on a large scale is the narrowing northern part of the Atlantic Ocean, where tides reach a height of 5 to 6 feet, and an extreme case is the Bay of Fundy, where they rise 60 to 70 feet. When running rapidly, tidal currents have considerable cutting power on soft shores, and in the Bay of Fundy the waters come in so loaded with mud that the people enclose them and allow the mud to settle, as a valuable fertilizer, on the land.

The sea is constantly changing its level on the shore, from the rise or fall of the land. If this change is slow the whole of the successively exposed shore is worked over, but if it is rapid there is very little effect, or else the land is benched as a result of successive rapid elevations and periods of rest, the benchings showing the various sea-levels at times of rest. The eastern plain of North America is the base of an old mountain-chain which has been cut down to its roots by the sea; while the kames of New England emerged from the sea so rapidly as to lose none of their delicate outlines.

Changes of sea level are commonly supposed to be due solely to a rise or fall of the land; but there may be several other causes. The ocean floor may as well change its level as the land; a glacial period may store up a great quantity of water on the land and so lower its level in the ocean; a thick ice-cap at one or at each pole may cause a distortion of the earth's centre of gravity and a consequent reärrangement of land and water. Again, as the earth loses heat

and its surface wrinkles, the tendency is for the land to rise and the sea-floor to sink; according as the fulcrum of this movement is to seaward or to landward of the shore-line, the land will seem to rise or fall.

Elsewhere than on the coast-line the ocean's work is constructive, the material cut away from the land being largely deposited just off shore, though perhaps one-fifth of its bulk is carried away in solution. Thus the continental shelf of eastern North America has been formed as a sort of tidal delta, with a width of 60 to 100 feet, and a slope of five feet to the mile. The deposits on the sea-floor are slowly added to by organic sediments, volcanic ash and possibly meteoric dust.

FREEZING AND FROZEN WATER. *Dana, pp. 687-702.*

The temperature of 32° F. is the critical point in the work of water. At this temperature it freezes, and in the act expands 1-11 in volume and 1-35 in length. In freezing in joint or cleavage planes, or between grains or crystals it exerts an enormous force in pushing apart and disintegrating the mass. In lakes and rivers, *anchor-ice* often forms on the bottom, inclosing large stones, etc. At length, rising to the top, it is pushed ashore and melts, leaving its burden brought from the bottom to form heaps or windrows on the shore. Ice gorges in a river often scour the bed and banks with great force. The lower courses of rivers in Arctic regions often become very indefinite from the freezing of their mouths and consequent formation of new courses by water from above.

Glaciers depend on the holding of the winter's snow until the succeeding winter, for their formation and existence. While rain expends not more than 10 per cent of its energy in the work of erosion, this form of water expends in erosion, probably 90 per cent of its energy. During a period of perhaps 150 years, the ice over the top of Iron Hill, R. I., took off 300 feet of its top. During the thousands of years since that time the rains have caused no ap-

preciable erosion. In a certain sense, a glacier exists wherever a mass of snow lies on an inclined surface, for it can be shown that the snow on our hillsides moves sensibly downwards in a winter. By the settling of this snow and its gradual conversion into ice we should have glaciers. Glaciers of two classes, which are, however, only different conditions of the same thing. *Valley* glaciers, like those of Switzerland, follow the courses of their valleys; but *continential* glaciers, like those of Greenland, are valley glaciers which have grown so as to overtop the hills, and can move, if thick enough, without regard to valleys, dragging their lower parts with them and riding over obstacles, or cutting them down as in New England and Canada in the last glacial period. The work of a glacier is done chiefly by the rasping action of the rocks frozen into its under surface, and is proportional to the thickness of the ice. A glacier moves faster at the top than at the bottom, at middle than at sides; and faster in daytime, in warm weather, and in lower valleys than under the opposite conditions. Its motion also increases somewhat with the slope but is not proportional to it, varying from one to four feet per day. No mention of this motion was made by any author until the 17th century, and no curiosity was awakened as to its cause until the beginning of the present century. Then the first thought was that they simply slip down hill. Later, it was suggested that the water which flows over the surface gets into the pores of the ice and, by freezing and expanding, forces the ice ahead. Another idea was that the strain on the ice causes it to break into fragments and that then, after sliding forward it settles together and refreezes. Principal Forbes of Glasgow suggested that the motion of a glacier and its conforming to irregularities of its valley are due to its being a plastic body like a mass of tar; but the objection here is that such plastic bodies are extensible, while ice is not. Mr. Ruskin proposed the theory that a glacier consists of molecules or fragments

which slip over each other like a pile of "wet herrings." Prof. Tyndall's theory was that strain or pressure causes the particles of ice to melt and fall forward until relieved, and then to refreeze. Now, Dr. Jas. Croll offers the explanation that heat from the sun or the interior of the earth passing through a molecule causes it to melt, and then passing on, allows it to freeze again, having meanwhile fallen forward a little. The objection to this is that many swift glaciers continue to move when all temperatures are below 32°. However, probably nearly all these explanations contain some truth and it is no doubt true that the motion of a glacier is due to a complicated series of causes. But how did the great continental glacier move over North America against the slope of the land and over mountains? Under a very thick mass of ice the bottom part will remain fluid from pressure. Getting heat from the earth this water would move forward, carrying the ice-sheet whose front part, resting on the rocks, would be the region of erosion as it ploughed across country. The retreat of an ice-sheet is not due to a backward movement, but to backward melting faster than sheet moves forward.

The work of glaciers (*p. 698*) is no longer important on the earth's surface. During the last glacial period, the surface of New England lost hundreds and perhaps thousands of feet of material. Much of this was carried away, as impalpable mud, into the sea. As one follows the Atlantic coast northward, he finds the continental shelf rapidly widening as he comes within the limit of glaciation. This excess of width is doubtless due to great deposits of material taken from the land by glacial action. Latitudes above 40° may be said to be subject to this erosion. As glacial records are temporary, the evidences of past glacial periods are limited. These records are of three sorts: scratched and moulded surfaces, deposits of boulders, gravels and clays, and deposits which have been changed by the action of the sea.

But we may be sure that several or many such periods have occurred in the earth's history, and have had nearly the same extension as the last. In the lower Cambriam of No. Carolina we find undoubted glacial deposits, and we have evidences of various similar periods since that time. Now what has caused these epochs of glacial conditions? It must be remembered that the necessary conditions for such a state of things are but slightly different from the present, and different only in adjustment, not in range. At a distance of three or four miles above the earth's surface, glacial conditions are permanent. The doubling of the present snowfall of New England would start glaciers in the White Mts. An early theory of the cause of the last glacial epoch was that it was started by the earth's cooling. Another was that as the earth drifts along in space it comes into regions which receive more or less heat according to their relations to the fixed stars, etc., and so its temperature varies. Still another theory held that changes in the earth's climate are due to changes in its geography and the consequent changes in the distribution of heat by ocean currents. Thus if the Japan current were to get into the Arctic O. (see p. 6) the rainfall there would be greatly increased and the glaciers much extended for a time, until the air became so much warmed as to cause them to disappear. If the strait between Florida and Cuba were to close completely, as it is gradually doing, the climate of Europe would become greatly modified (p. 6). Changes in mountain chains may greatly modify rainfall. Climatic conditions are very temporary and changeable.

But these causes are not sufficient to cause a great glacial period. Dr. James Croll offers the hypothesis that as the ellipticity of the earth's orbit varies irregularly, it must happen that when the orbit is most elliptical, one pole will get its summer when the earth is nearest the sun, and the other pole will get the same season when the earth is farthest from the sun. Thus the former will have a short, hot sum-

mer, while the latter will have a long, cool one. This and other astronomical causes combine to produce marked differences in the summers at the two poles, the conditions being just reversed for each pole every 12,000 years. Dr. Croll thinks that in a hot, short summer the rapid melting of the snow of the long winter would soon cause fogs which would shield the remaining snow from the sun and prevent its entire melting. These conditions at the North Pole would also increase the strength of the trades in the Northern hemisphere, and so pile up the ocean waters to the South, thus lessening the warm, northward currents and the temperature of those regions. This loss of heat would admit of the establishment of permanent glacial conditions. This theory assumes that there is a regularly alternating glaciation of the Northern and Southern polar regions and herein is its difficulty, for glaciers seem now to be retreating at both poles. These glacial theories well illustrate the method of scientific investigation. To explain given phenomena a hypothesis is put forward; and it must be tested by all known facts and laws, and slowly and laboriously verified before being accepted.

We have thus seen how profoundly the earth's climate is dependent on conditions which are very variable. Outside of a narrow zone extending from one mile below to three or four miles above the earth's surface, life is impossible. Yet since the beginning of life there have never been so great extremes of cold or heat in all parts of that region simultaneously, as to destroy that life which has gone on in an ever ascending column. Life has been pushed back from the poles by cold and perhaps from the tropics by heat. Large herbivora grazed up to the edge of the ice sheet in both Europe and North America. Therefore all changes in temperature must have been gentle and gradual, and we must not look to sudden causes for the explanation of these phenomena. They are doubtless due, not to single causes, but to the coincidence of various causes. *Icebergs (p. 701.)*

WATER AS A CHEMICAL AGENT. *Dana, pp. 702-712.*

Above ground, water is not important as a chemical agent. It gets under ground in two ways; by soaking in, and by being built in during the process of deposition. Water soaking into the soil keeps slowly moving, taking up CO_2. That which is built in has little motion and is practically dead. Both acquire heat and the former gains also motion. Its motion is, however, usually slow and seldom has any mechanical effect. An exception to this rule is seen in the formation of *caverns*.

These are of four classes: (1) those formed by underground water in limestone districts, never going below the drainage level; (2) those formed by the sea, extending back only so far as the waves can exert a cutting action on the rocks; (3) those formed by the solution of limestone by hot waters rising from the depths of the earth, which may extend to any depth, and may become filled by metallic deposits; (4) those formed by the flowing out of lava from beneath a cool crust on the surface.

The most important and most numerous group of caverns is the first, including the ordinary limestone caverns. They occur chiefly in pure limestone, as calcite, and aragonite, but not in dolomite. In a cavern country, no valleys and no brooks are to be seen, but everywhere pit-like depressions or *sink-holes*. At the bottom of each of these is a rift or cylindrical tunnel leading downward, often with its mouth overgrown by vegetation. Passing down through one of these openings, one meets first a solid layer of often sandy rock which determines the surface of the country and is called the *topographic resistant*. Below this layer comes the main chamber or "*dome*" of the cave into which shelves of harder rock often project from the sides. From the tops of these shelves galleries usually lead off, sometimes ending blindly, but often connecting with other domes. At the bottom of a dome is usually a mass of quartzose fragments. During a rain-storm the water, pouring through

the sink-hole, churns up this mass and grinds the bottom of the dome still deeper, taking up the limestone in solution and carrying it away by side-channels. Water, percolating through the joint-planes and interstices of the rock and dissolving limestone on the way, reaches the roofs of the galleries. Here, in a dry gallery, it may wholly evaporate and deposit its lime, forming slowly an icicle-like *stalactite* by successive deposits. Or, losing CO_2 and partly evaporating, it may deposit a part of its lime, while the rest, dropping to the floor, there deposits the remaining lime. In this way are formed, by slow growth, a stalactite and its corresponding *stalagmite*, which finally fuse into a column. The formation of numerous columns close together may form a partition wall, or even wholly refill a gallery with limestone. This cycle of excavation and refilling is constantly in progress. The formation of caverns is one way in which rocks wear out from beneath, and is a more effective means of erosion than surface wear. The solution of lime by filtering waters illustrates a little recognized, but important form of erosion; namely, *interstitial* erosion. The roofs of caverns often fall in and expose the streams within. A limestone natural bridge is a remnant of an old cavern. Caverns are very numerous in limestone districts and completely honeycomb the rocks. They are, as we have seen, complicated systems of underground passages with nearly all their openings closed up. But a single entrance to the Mammoth Cave in Kentucky is known, yet it has 150 miles of galleries. The temperature of caves is very constant, varying but little from 60° F. in the U. S. Consequently there is in summer an outrush of air from the mouth, and in winter an inrush at the same point, varying in strength with the size of the cave. These currents are compensated by currents in opposite directions at the sink holes. A strong current of air through a hole in the ground indicates the presence of a cavern of some size. The air of caves is very pure, as decay hardly takes place at all. Meat left there dries up without putrefying.

Caves are very interesting to the naturalist, as affording much information on the history of life. They have been the dwelling-places of many animals, including man, and the bones of the old inhabitants and their prey are often found in them. And not infrequently, early human implements are found. The sink-holes, too, form dangerous traps for land animals, which fall in to die. Besides, many species of animals live habitually in caves, though of course dependent for food on importations from without, since life cannot be continuously kept up without sunlight. Cave animals well illustrate the effects of entire change of conditions on living things. They show that disuse of an organ leads to its suppression, even when so complex a structure as the eye. We have among cave-animals, all the stages in the disappearance of the eye, from simple loss of function to entire loss of structure. The forms of cave-life show close relations to outside forms, but always modified to suit their changed conditions of life.

For further chemical work of water, see pages 703–711 of Dana.

In brief, then, water plays two important general parts, an organic and an inorganic one. It supports life through its containing a large proportion of oxygen, through its great capacity for heat, and through its power of dissolving inorganic substances. It works mechanically and chemically in the liquid and solid states, in erosion, stratification, crystallization, etc.

Heat. (*Dana, pp. 712-782.*)

SOURCES OF HEAT (*p 714.*)

Heat comes to the earth from the stellar spaces where the existing bodies may be divided into three classes,—suns, planets, and satellites. The first are still so hot as to be luminous; the second are partly cooled, but still hot internally; and the last are wholly cold. It is now generally considered that all the systems of the universe have arisen from nebulous conditions of matter, such as are at present

seen in space. Many astronomers believe that the heat of the bodies formed from nebulae has been generated by the falling together of the particles of matter forming them and the conversion of their energy of position into heat energy. But, according to Helmholz, this could give only heat enough to allow for 20 million years of cooling to bring the earth to its present condition, while geology indicates that the earth's development must have taken a much longer period. Dr. Croll here suggests that the nebulae have arisen by the meeting of two bodies, each of a mass equal to one-half that of the sun, and that by this impact they have acquired an enormous quantity of heat, which he computes to be sufficient to require 150 million years of cooling to bring the earth to its present condition.

The sun's heat affects a belt extending from 100 feet below to five miles above the earth's surface, approximately. Much of the heat received is quickly radiated back, but much more is taken up by water and otherwise.

Another source of heat is the interior of the earth, and the effects of this internal heat are produced in two ways,—by loss of the heat, causing shrinkage, in connection with the migration or outflow of the heat from the centre to the surface, and directly. The earth loses each day heat enough to melt from 20 to 200 cu. mi. of ice. Leibnitz saw that the earth must be considered as a hot mass with a cool outer crust, as shown by volcanoes, by the fused appearance of the upturned edges of deep strata, etc., and it was for a long time believed that the interior is liquid. But geologists began to doubt this belief, from the fact that liquid lavas stand at different heights in adjacent cones of volcanoes, which could not be if they were parts of a connected fluid mass. Besides, it has been shown that a solid crust a mile in thickness on the surface of a liquid globe, would sink by its own weight into the liquid below; and astronomers have shown that there would be no nutation of the earth's axis if its interior were liquid. Sir Wm. Thompson has computed

that the earth's interior must have the rigidity of glass, and perhaps of steel. But we know the temperatures there to be far above the melting point of rocks. This rigidity may, then, be caused by the overcoming of the temperatures by great pressure.

The solidifying of the earth may have begun by cooling at the outside and the falling in of successively formed crusts until the whole became solid; or it may have begun at the centre from pressure and have progressed outward until a thin liquid layer remained on the outside, when the surface would cool and be supported by the thin viscous layer between it and the solid central mass. The earth is now, perhaps, in the latter condition.

VOLCANOES (*pp. 722-748*).

Volcanoes are scattered over the sea floor and along the shores, few active ones occurring more than fifty miles from the sea. As in process of geological development the sea has abandoned a region, its volcanoes have become extinct. All extinct volcanoes are near old sea-beds. These facts indicate a causal connection between volcanoes and the sea.

The remains of volcanic ash, pumice, etc., are not very abundant, but they indicate that volcanic activity has never been much greater than now. It was formerly believed that it has been much greater, because of the greater numbers of volcanic tubes found in older rocks. But this is understood to be due to the fact that when a tube is closed by the laying down of strata above it, and another tube is formed later, the last has to penetrate all the layers then existing to reach the surface, so that, the older a given bed, the more it is penetrated.

A volcano is an opening in the earth's crust from which heated matters are usually projected as from a gun, by an outrush of gas, accompanied by explosive action. The force and velocity of the escaping gases are enormous, and this outrush constitutes the essential part of the eruption, the solid and liquid matters being no more essential than a

bullet to the firing of a gun, though they are usually present. This gas is shown to be largely steam by the fact that it condenses in the upper air and falls in torrential rains during the eruptions. There is probably also much hydrogen present, from decomposition of water, which recombines in upper air to form water. The cone of a volcano is formed by the heaping up of solid materials thrown out from the crater, and varies in size and shape according to the nature of the materials. These consist of cooled lavas, blown lavas, pulverized rocks, etc. Parts of this material are sometimes carried to a height of 30-40 miles, and perhaps sometimes out of the power of the earth's attraction to draw them back. Much of the material is reduced to such fine powder as to float for years in the earth's atmosphere.

The causes of volcanoes and the source of their supply of water have been the subjects of many theories. One theory was that the water enters through crevices in the rocks from the sea. Another suggested that, as water penetrates the earth against pressure (see p. 14), it enters earth through sea-floor and so gets into volcanoes. The objection to this is the fact that it might penetrate equally well on land, and so would not require the presence of volcanoes near seas. The present view is as follows: water is built into rocks in great quantity by deposition and crystallization, and the effect of more deposition is to raise the temperature of the beds below at the rate of 20° F. for 1000 feet of deposit. Now, as the sea is constantly cutting away material from the land and depositing it on its bottom, the temperatures of the buried strata of the sea-floor are constantly being increased. The pressure of superposed beds prevents the vaporization of the water in a given very hot stratum. But should a crevice be formed and the pressure be released, the water instantly becomes steam and escapes through the crevice, often driving before it much solid and molten material. A hypothesis in geology is not often verifiable by laboratory experiment, but we have to look for large natu-

ral experiments. In case of volcanoes, we find a confirmatory experiment in burning coal and lignite mines which closely simulate volcanic action, especially where their mouths have been closed and new outlets have been formed through which heated gases escape, and about which, in a few cases, small cones have been formed.

The functions of volcanoes are important. If buried waters were never returned to the sea, it would be largely diminished in volume. This return is largely accomplished through volcanoes which also return much other buried material to the surface. Great quantities of carbon are stored up in the limestones and other rocks; and, indeed, it would not require very long, geologically speaking, at the present rate, to remove all the carbon from the air, if none of that constantly being stored up in the earth were ever returned. So, too, oxygen buried in the form of oxides, etc., is returned to the air by volcanoes. Not much volcanic material is carried to the deep-sea bottom. The solid matter is largely pumice, which floats for a long time till its imprisoned air is released by its decay. The fine dust and ash thrown out also fall slowly, forming deposits often at great distances or even all over the earth, as in case of the Krakatoa eruption. The great amounts of heat in volcanic materials seem to have very little effect on surrounding climate. This is probably because the gases are thrown so high as to give up all their heat to the surrounding cold space by their rapid lateral diffusion. The volcanoes of the earth and other planets are a probable source of meteorites, many of which resemble lavas. In these is our only hope of learning anything of the life of other planets.

Lava is heated, rocky matter which is kept solid by pressure while working toward the vent, and at once becomes liquid on reaching it, being relieved of its pressure. As it rises through the crater, it cools rapidly from the expansion of its contained gases. Lava usually contains unmelted fragments and crystals, and flows freely, sometimes filling river-beds or valleys. Many lavas decay rapidly while

others remain long unchanged, according to their different chemical compositions. Towns subject to lava-flows generally depend for their water supply on cisterns; and the water in these, being vaporized by the heat of lavas during a flow over them, finally breaks through the stream of lava, forming a miniature volcano, until the steam has escaped. Mount Etna has its sides covered with small cones, which act only once. These are probably caused by uprushes of lava through rifts into buried beds of ice or snow, which are converted into steam by the heat of the lava and so burst out through a newly formed crater. These small craters remain, though inactive, until buried up by eruptions from others.

Dikes are formed by volcanic action in which the lava does not reach the surface. (Formation described on p. 13.) Facts which favor the belief that dikes are formed by the melting of stratified rocks, are that they contain crystals having water of crystallization, and their materials differ greatly in different places, showing them to be dependent on local deposits. Dikes are common in nearly all rocks, filling the frequent rifts. They may be distinguished from true volcanic passages by their edges being sharp and distinct while those of the latter have a molten appearance.

While volcanoes are caused by the heating of waters built into the rocks, waters which have penetrated from the surface and become heated often return as *thermal springs* or *geysers*. (*p. 749.*) The penetration of water to great depths is a usual occurrence, all rocks in mines furnishing a considerable amount of water. In crevices this water moves often very rapidly, but in interstices very slowly. In horizontal beds, water can only penetrate to the first impervious stratum; but where strata are tilted, as is usual, it may follow a pervious stratum to great depths, its solvent power increasing as it goes down.

METAMORPHISM (Dana, pp. 754-770).

Changes in rocks may be caused by pure water, by water containing other substances, or by highly heated water. It

may act through crevices or through interstices of the rock, which is taken up by it, transported, and deposited again. Rock may be taken up from any condition, but is deposited only in the crystalline or concretionary form. The crystalline state is one of repose, being less affected by water than others. This metamorphism may be constantly kept up, and is attended by a slow migration of water through the rock.

MINERAL VEINS (*pp. 770-782*).

Water, coming up through a fissure and losing its solvent power as it rises, lays down the substances held by it in solution at different heights in the fissure, according to their various solubilities. These substances have been taken largely from the beds bordering the fissure. Vein-fissures are due to faults or to joints, typically. Where there is no dislocation of strata, we get *gash-veins*, which are formed by the shrinking of a stratum from interstitial erosion. Hence they occur usually in but a single stratum and run out above and below.

Where a dislocation has taken place, we have dislocation veins, formed by the failure of warped surfaces, which have been slid on each other, to fit together. These are always ragged and irregular, and are formed by mountain-building strains. They may be rent by a second strain after being filled. No such things as regularly open veins exist. At the crossing of joint-planes we may have cavities filled by ore-deposits, and the spaces may be swelled or spread apart by the growth of these deposits. Mineral deposits may also occur in chambers formed in limestone by hot waters from below, or in interstices between pebbles or grains of sand.

DISTRIBUTION OF METALS.

Metals of value in the Arts may be divided into useful and precious metals. The value of the latter class has doubtless come about through their early use for ornament. At first, only native metals could be used, and man was without the useful metals and confined to stone and bone for cutting, etc. Smelting processes are recent; and especially

in the present century have new metals been brought to use. Nearly all have now been conquered, probably, except that which would be most useful of all owing to its properties, aluminum. While very light, it is very rigid and resists oxidation.

Iron is the most important and one of the most abundant metals, and most closely related to our life. It is taken by plants from the sea, and so built into the rocks, but in small proportions. Water containing CO_2 may dissolve it, and flowing into a bog, may gradually deposit it there as an oxide, forming *bog iron ore*. Or, water holding iron in solution may work downward through the rocks until it reaches a limestone bed, where, having more affinity for lime than for iron, it will take up lime and deposit iron, transforming the bed into one of iron carbonate. This bed may further decay, losing CO_2 and be transformed to a red or yellow iron oxide (Haematite or Limonite). These beds of iron ore are very important and easily mined. Or, further, such beds may become metamorphosed, forming dikes or veins, or one of the crystalline ores of iron. We cannot foresee the exhaustion of the iron resources of the world. The most iron beds are very old, belonging to early geologic time. Their distribution is very uniform, but their value depends on the proximity of fuel for smelting.

Copper is much more irregularly distributed than iron. Its beds are very old and chiefly exposed in northern parts of continents, where there has been most wear. The richest deposits are in North America, and the only important source of native copper is the Lake Superior region.

Tin always occurs as an oxide, and is very little produced in America.

Lead is very widely distributed, and in old strata.

Zinc occurs as an oxide and usually with lead.

Silver and *Gold* are widely distributed. Silver is almost always present with lead, and is very abundant. Gold occurs in paying quantity only occasionally.

Relation of metals to currency.

Consequences of Earth's Cooling. (*Dana, pp. 782-836.*)

These consequences are such as are due to simple loss of heat, and the shrinkage of the earth is probably due wholly to this cause, although the moon's condition makes us doubt this. But perhaps the moon's surface is not folded because not stratified, since the strata of the earth slip on each other, in folding, like sheets of paper.

The loss of heat is accomplished in two ways, by direct outflow in all directions from the interior, varying at different points, and through volcanoes. It has been going on ever since the earth's formation. Since the hardening of its present crust, the earth has probably not shrunk more than one-eighth to one-fourth in diameter. Meyer's calculations give one meter per 1000 years as the rate of shrinkage; this is probably the maximum.

FOLDING OF CRUST.

The external evidence of the earth's shrinkage are seen in the realized and unrealized contractions of the surface in *continental* and *mountain* folds.

The former are very gentle, and of great amplitude, while in the latter, the ratio of height to width is great. We may find very perfect series of mountain folds, varying from 60 miles to a fraction of an inch in breadth, but there are no connecting links between the largest of these and the great continental folds, thousands of miles in breadth. Continental folds are solitary and more or less triangular in outline, and point southward, while mountain folds occur in groups. Continents are pretty fairly distributed over the earth, though they tend toward the North Pole and toward one side of the globe, leaving the great basin of the Pacific Ocean on the other side.

Mountains are of two classes, those still forming and those whose formation is completed; that is, living and dead mountains.

In eastern North America the mountains were formerly very extensive; but their growth ceased long ago and

they are now largely cut down. In western North America the mountains are still growing, as also are the Alps. Many parts of the earth show no mountain-building change, but in the Archaean rocks mountain forces have everywhere left their record. Only small parts of the earth are influenced by these forces at any one time.

The average depth of the sea is 15,000 feet, while many mountains of the earth exceed this height; so that if mountains exist on the sea-floor (volcanoes excepted) some of them ought to project to form islands. As this is never the case and soundings do not show the presence of mountains below the surface, we must conclude that mountains are limited to the land.

The normal rate of mountain-growth is very slow. The foldings of thin beds are very regular, and faults are few; while thick beds show few true folds, but many breaks and faults. The amplitude of a fold depends on the thickness of strata involved. Here lies the probable difference between continental and mountain folds; the contraction of the inner half of the earth's outer crust may cause mountain foldings, while the contraction of the earth's inner mass may cause the folding of the whole outer shell and produce the ampler continental fold.

Mountains were until recently believed to be arrested waves in the strata; but they are now believed to be folds of strata produced by pressure and contraction. The simplest type of mountains is the simple row of folds, as seen in the Alleghany and Jura mountains; or we may have these folds raised on the backs of ampler ones; and a third set of still ampler ones, bearing the second, may occur. But curves alone rarely explain the contours of mountains, faults being usually present and important in their effects. Beside these causes, erosion is often very effective in determining the relief of mountains.

As the largest objects grasped by the mind, mountains have an intellectual and sympathetic interest, and perhaps,

also, because of their resemblance to architectural forms. Mountain folds are probably filled in from beneath by slow interstitial action of underpacking which accompanies and keeps pace with the slow folding. This helps also to produce the synclinals which occur on each side of the anticlinal. The part thus formed serves as a pedestal or tableland to support the mountain masses above.

EARTHQUAKES. (*Dana, pp. 804-806.*)

Earthquakes are the only non-constructive and paroxysmal phenomena with which we have to deal. They are shakings or vibrations of the earth, due chiefly to the elasticity of the rocks. These shocks occur in various regions of the earth, which are rather irregularly distributed over its area. They are felt on sea and land, on shore and inland, in high and low latitudes, at high and low elevations. Countries near together often have entirely different earthquake conditions. The southern parts of continents are apt to be specially liable to shocks.

Though the United States is comparatively free, it embraces three earthquake regions. The *Pacific coast* region has had one very destructive shock (1811). The region of the *valley of the Ohio and Mississippi* suffered very severely in 1811 from the "New Madrid earthquake" whose centre was in western Kentucky. Alluvial land along the streams sunk, in many cases, with its forests, below the drainage level, forming wooded lakes. This disturbance lasted for two years, steadily decreasing in force. The first shocks were felt very far from the centre, but the last caused only a continuous tremor of a few square miles. Even log cabins were thrown down by the early shocks. The *New England* region is quite remarkable. An earthquake of strength was felt in 1685 all over New England. In 1727 a disturbance began which lasted for several years locally, and was quite noisy, though not very violent. In 1755 a very severe shock occurred, which was the first to be scientifically observed. This was done by Professor

Winthrop of Harvard. Most of the chimneys in Boston were thrown down, and bricks were thrown to some distance, indicating a considerable rocking of the earth.

Earthquakes are most powerful and destructive in the Andes. The shocks are sometimes accompanied by the opening and closing of crevices in the earth, which often engulf animals or buildings.

Loose materials on a steep slope are slowly working downward, but may be jarred down suddenly by an earthquake shock, as in Jamaica in 1686, when forest-covered mountains were denuded during a night, leaving only bare rock, while the rivers were choked by the mass of material thrown into them. Thus earthquakes may greatly aid the work of erosion.

Water readily transmits an earthquake shock, often causing great destruction among fishes. Ships have been wrecked, or have been thrown upward so rapidly by a vertical shock, as to have the masts driven through the bottom.

For earthquake waves, see p. 27.

An earthquake shock is like that which runs through any body which is struck, waves running out from the centre and reflection waves being sent back from any substance of greater density which is met. The latter greatly complicate the original waves and cause movements in many different directions. The shock is probably caused by a fracture or fault suddenly formed, and passes out vertically and obliquely from its centre to the earth's surface. The cause was first shown by Mallet, from a careful study of two earthquakes. The maximum disturbance in an earthquake does not probably exceed three feet; and one of a few inches produces a strong shock. The older rocks contain innumerable faults everywhere, and each of these probably represents a shock.

Earthquakes have interesting relations to human civilization. The southern limit of Gothic architecture in Italy

and Spain is set by them. Houses in China and Japan are built with special reference to their occurrence, being slightly attached to the earth and very light, particularly in the upper parts.

High towers, like pagodas, in China, have heavy beams or logs hung from their tops, to act as pendulums to keep the centre of gravity within the tower, in case of an earthquake.

IV. Historical Geology.

Life. *Dana, p. 114.*

An organic being is an association of matter which has the power of taking material to itself and of appropriating both its matter and its *force*. Other associations of matter can add to themselves new matter, as crystals and concretions; but no other has the power to appropriate force or energy to its uses. Organic life is determined by the solvent power of water between the temperatures of 32° and 100° *F*. To make organic life possible, very many conditions must be realized simultaneously. The earth's surface seems to be the only place in our solar system where it is now or ever has been possible.

In order to have an advance in organic structure, it seems necessary to have a succession of generations, each of which tries to solve the question of improvement and passes away as soon as possible after its growth is done and its reproduction accomplished. The result is a generational character of the organism in which, also, it differs widely from other aggregations of matter, a crystal or a molecule being unlimited in its period of existence.

Organic life represents continuity of effort. At first, the attempt is only to maintain the individual and to reproduce the species; and plants never rise above this condition. The lowest forms of life are not distinctively animals or plants, but simply *organisms*. From this common base-

ment, two great branches go off. In the animal branch, we have besides the merely vegetative functions, the institution of sentiency. At first this is limited to perception of the outer world through reactions which are purely automatic, but from this comes up the intelligence. The result of the development of intelligence is that animals are modified not only with reference to the vegetative functions, but also with reference to the fitting of the body to become the seat of intelligence. To be suited to this purpose the creature needs a mechanism of intelligence, a nervous system and organs of sensation which will enable it to perceive by touch and to be conscious of light and sound vibrations. From many different original sources, the animal kingdom works toward organs of this sort. Eyes and ears are invented several times and on different plans among animals. Through the will the various sensations are utilized.

To be fitted for the uses of intelligence, an organic structure must have, also, the power of motion. Motion requires a disposition of the parts with reference to the axis of motion, as seen in motile animals. The two sides must be balanced, right and left, as in nearly all moving creatures, and as is recognized in the construction of instruments of locomotion, ships, wagons, etc. Next, there must be means of carrying out the purposes of the intelligence, as through the exercise of the will organs. Hence are developed organs of motion, of active defense, etc.

It is interesting to note here that while all plants tend to associate themselves into communities by the grouping of many individuals, the separate phytons, into tree or herb, this communism characterizes only the lowest animals, being seen in the Protozoa, Radiates, and lower Mollusks, because it is a condition not at all suited to the needs of intellectual creatures.

Three great successes in intellectual development occur among animals; in the Insects, in the Cephalopod Mol-

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lusks, and in the higher Mammals. In the Vertebrates there is the greatest recognition of the nervous system, by devoting a special protected region to its occupation.

The great need of organic forms is to bridge over the gap of death between the generations, to enable the living generation to give the greatest possible help to its offspring, in food, experience, etc. The more completely a generation can be possessed of the knowledge and experience of its predecessors, the better prepared and equipped will it be to make improvements and to raise itself to a higher plane. The first condition of the egg or germ is very simple. The parent throws off a part of itself which develops into a new animal. This is always the essential part of the process, but by steps the more complex egg is instituted, containing a store of nutrient matter for the sustenance of the developing young. This store increases as we rise in the scale of life, in both animals and plants. The spore of a fern is microscopially small, but the seeds of the grains contain great quantities of nutriment of which man and some lower animals avail themselves for food. Indeed, without these grains, man's career would have been impossible.

ANIMAL KINGDOM. *Dana, p. 116.*

All living and fossil animals may be included under *five* heads or types of structure.

The Protozoa are small and comparatively simply animals; but it should be remembered that an apparently most simple organism is a very complex structure.

The Radiates have their parts arranged radially about a vertical axis. Many of them are associated in colonies and most are sessile; but in the higher forms we get simple individuals and the power of motion. The latter leads to a struggle in the very highest forms to attain a bilateral symmetry adapted to motion.

The Mollusks are animals with soft bodies, usually covered with a shell, and bilaterally symmetrical. There is no very distinct head except in the Cephalopods.

The Articulates are bilaterally symmetrical animals whose bodies are formed of successive ring-like segments arranged along the longitudinal axis, and each capable of producing appendages. Very many of these animals have the body covered by a hard, jointed, external skeleton. This group presents great structural successes. There are more Insects than of all other animals.

The Vertebrates are the successful group intellectually. They have a jointed internal skeleton, with a special bony case for the central nervous system. None of this group has more than two pairs of appendages.

THE GEOLOGIC RECORD.

We cannot hope to follow the record of the rocks back to the beginnings of life. The earliest creatures must have been so delicate and perishable, that they would leave no trace for long ages in the early development of life. Then too, the early rocks have been so metamorphosed by heat and crystallization that fossils in them must be destroyed. The older a rock is, the greater has been the chance for metamorphism. We have but one evidence of life below the level of the fossiliferous rocks. This is the existence in very old formations of thick beds of limestone and graphite, both of which are known to have been formed in more recent times by organic agencies.

From the times of whose life we have records in the rocks, few of the living creatures have been preserved to us, so that the record is extremely imperfect. Of the multitudes of animals which have lived in New England in the last 50,000 years, not a trace has been found. This is because animals, and especially land animals, are preserved only by chance, such as floating to sea and being buried under deposits on its bottom, being overwhelmed by volcanic action, or becoming mired in swamps. So few animal and plant bodies are preserved from entire decay, that the remains we find are very fragmentary. The succession of life on a given area in different geologic periods may be explained by migration brought about by changes in climate, combined with the evolution of species.

GEOLOGIC PERIODS. (*Dana, pp. 136-604.*)

The *Lower Silurian* formations are known in Northern Europe and the Eastern United States, and recently have been discovered in the Rocky Mountains. They vary from a few hundred to many thousand feet in thickness, and are much changed by baking and the percolation of water.

In these rocks the tests of Protozoa and Radiate remains abound, as well as lower Crustacea, especially Trilobites which here reach their maximum development, and low Mollusks. This period probably represents from ten to thirty millions of years.

Organs of touch were well developed in very early animals; eyes were present in very many of the forms, and were chiefly of the many-facetted type. These earliest had, probably only the power of distinguishing between light and darkness, not that of forming an image. There is no evidence of a sense of hearing in any of these animals.

Our only remains of land life in this period which we have, are some bits of Ferns and a few Scorpions. Yet we know that there must have been considerable exposed land, because the maintenance of sea life requires land to supply those materials to the sea which are being constantly taken from it by living creatures. Vertebrates do not appear until the *Upper Silrian*, when a considerable variety of pretty high Fishes is found abundantly. The Fishes probably developed in some limited area during the Silurian and were set free into the oceans by some geographical change near its end.

Climatal evidences of the Upper Silurian are interesting. The prevailing temperatures must have been between 32° and 100° F. In the Silurian conglomerates we have indications of several glacial periods, some much greater and farther reaching than the last. We find, also, rock salt deposits, which require enclosed basins with excess of evaporation over supply for their formation.

There are preserved old sea beaches which show raindrop prints indicating the prevailing winds when they fell.

The *Devonian* time is marked by the great development of the Fishes and the increased land surface of the globe. The first Fishes were heavily mailed with thick bony plates. Following their appearance, nearly all the lower animals show the effects of the presence of a new enemy by the development of protective devices. Chief among these are long spines which enable the animal to subtend a larger angle than that of fishes' jaws.

The Crinoids are a group of sessile radiated animals, with stems bearing calyces and branching arms, now nearly extinct. While they were developing they had no great enemies. When Fishes appear they begin to die out. Some forms develop spines and resist for a time, but finally disappear almost wholly.

The *Carboniferous* age is a very interesting one, and very well known because of the profit of working the coal deposits.

The deposits of coal during this period were made chiefly on the shores of the Atlantic Ocean, north of the Equator. Most of Europe and North America were below the sea during the Silurian, but a large part got above the surface by the end of the Devonian. These lands were low and flat and had a warm and humid climate, favoring plant growth. So a rich vegetation sprung up, including Ferns, Cycads, and Conifers, chiefly. Swamps and climbing bogs were very common, the latter even overrunning the hills. Below the coal beds are found fire-clays, that is, clays without alkalies, the latter having been removed by the plants which grew in the soils. Above the coal layers are strata of slates and sandstones indicating a subsidence of the land after the period of rich vegetation.

In some there occur from 40 to 120 sets of these layers, indicating as many successive oscillations of the land. The best explanation is that of Dr. Jas. Croll, who suggests that the variations in climatical conditions, due to the eccentricity of the earth's orbit and other causes (see p. 32), are here recorded; that the extremes of climate, 12,000 years apart, are represented, the warm periods by

the coal layers, which are remains of their vegetation, and the cold periods by the rock strata and glacial conditions. These alternations of level are just such as were experienced during the last glacial period, which seems to confirm Dr. Croll's theory. The idea that the atmosphere contained more CO_2 than now, during this period, cannot be sustained. Experiments show that plants are hindered rather than helped in growth by a much greater proportion of CO_2. There were living on land at this time many animals nearly related to many of the present who cannot endure an excess of CO_2. Finally, there were deposited in the Jurassic, about the North Pacific Ocean, beds of coal as large as those of the the Carboniferous while Reptiles and lower Mammals were living on hand. All these facts go to show that the atmosphere of the Carboniferous was essentially the same as that of to-day. All the North American fields of coal are probably a part of one great original deposit, whose connecting parts have been worn away though still traceable in many places.

The coal measures give us the first land Vertebrates and many of the first air-breathers. This new function opens up a new field of possibilities to animals. Among the forms of this time is a gigantic tadpole-like creature which probably developed into a frog-like form.

In passing from the Carboniferous to the *Mesozoic*, we pass a great gap, especially in organic development.

The *Triassic* is characterized by the great development of Reptiles. The group probably originated earlier, but we have no acknowledged fossils from earlier horizons. The Reptiles develop toward a greater power of movement, and toward a system of defense. The latter finds its highest development in the Tortoises. At this time great swimming and flying Reptiles inhabited the sea and air, and the gigantic Dinosaurs, among the largest animals that ever lived, inhabited the land.

The latter must have reached 65 feet in length, 13 or 14 feet in hight, 20 tons in weight. After a time the Reptiles begin to decline apparently from an exhaustion of vital

force, much as in an old individual. At the end of the Jurassic they were past their prime, and at the end of the Tertiary, mostly gone. Only a few scattered remnants of the once great group now remain.

Pretty well down in the series we get traces of the beginnings of Birds and Mammals. The early Birds were Reptilian in their characters, with strong toothed jaws. They were all warm-blooded and feathered, and the earliest known had a long, lizard-like tail.

There is little doubt that the Mammals came off from the Reptiles pretty low down. The great difficulty in the way of development of intelligence offered by the brevity of life of a generation is better met the higher we go in the line of development. A fish lays very many and very small eggs and the proportion of these which ever become mature fishes, is extremely small. In the Reptiles the eggs become larger and fewer; in Birds the eggs are also brooded by the parent or kept under the influence of some other source of warmth. In this series the possibilities of the egg-laying habit are quite exhausted.

In the development of the Mammals there is realized what has long been sought in lower groups, the connection of the young with the mother.

In the *Jurassic*, the mammals were all marsupials, or mammals in which there is no connection between mother and young, and in which the young are born very imperfect and placed in a pouch on the mother's abdomen, where they are attached to teats, and develop fully.

As we pass to the *Tertiary* period, we are conscious of passing the line between the stranger life of the past and the familiar life of the present. The animals begin to be much like the living forms. Here we find the first animals with a true placenta or organic connection between mother and developing young, a feature afterward of greatest importance in the advancement of the mammalian series. We find also modifications of the primitive five-toed foot, especially that for running, where we find a series leading to the cloven-hoofed, and another to the solid-hoofed ani-

mals. The latter series is well illustrated in the line of the horses (*Dana, pl. X.*), in which we find a gradual loss of lateral digits and strengthening of the central one. A further proof of the origin of the horse's foot in this way is the occasional development of lateral hoofs on the legs at the ends of the splint bones, which are the remnants of lost digits.

There is traceable also in the Mammals a steady increase in the size of the brain, and in the complexity of its convolutions. This distinct progress in the apparatus of intelligence must indicate a marked development of intelligence itself.

Intellectual development has been believed to have been chiefly on the line of rationality, that is of memory and understanding of relations of cause and effect. But this is not the most important line. The beginnings go back to the separation of the sexes and the institution of the sexual and parental instincts. The herding instinct arises very early, and with it the instinct of defense by the leader of the herd. Hence arise the sympathies in general, at first blind, unreasoning impulses, and always remaining so to a large extent, but somewhat controlled and directed by reason when it begins to appear. It is the sympathies, guided by reason, which lead to our social organization, and are now extending themselves to all men and even to the lower animals.

The plants of the *Tertiary* were much like those of the present. They now began to be larger-seeded, and so more helpful to their offspring. And we find among flowers, first during this time, the development of wonderful interrelations with insects, for the purpose of securing cross-fertilization as a preventive of the dangers of continual close fertilization. In this, both flowers and insects become much modified and adapted to each other, the flowers developing bright colors, odors, and nectar to attract the insects.